



Prehospital Echocardiography During Resuscitation Impacts Treatment in a Physician-Staffed Helicopter Emergency Medical Service: an Observational Study

Rein Ketelaars, Christian Beekers, Geert-Jan Van Geffen, Gert Jan Scheffer & Nico Hoogerwerf

To cite this article: Rein Ketelaars, Christian Beekers, Geert-Jan Van Geffen, Gert Jan Scheffer & Nico Hoogerwerf (2018): Prehospital Echocardiography During Resuscitation Impacts Treatment in a Physician-Staffed Helicopter Emergency Medical Service: an Observational Study, Prehospital Emergency Care

To link to this article: <https://doi.org/10.1080/10903127.2017.1416208>



© 2018 The Author(s). Published with license by Taylor & Francis© Rein Ketelaars, Christian Beekers, Geert-Jan Van Geffen, Gert Jan Scheffer, and Nico Hoogerwerf



Published online: 22 Feb 2018.



Submit your article to this journal [↗](#)







View related articles [↗](#)



View Crossmark data [↗](#)

PREHOSPITAL ECHOCARDIOGRAPHY DURING RESUSCITATION IMPACTS TREATMENT IN A PHYSICIAN-STAFFED HELICOPTER EMERGENCY MEDICAL SERVICE: AN OBSERVATIONAL STUDY

Rein Ketelaars, MD , Christian Beekers, RN , Geert-Jan Van Geffen, MD, PhD ,
Gert Jan Scheffer, MD, PhD, Nico Hoogerwerf, MD, PhD 

ABSTRACT

Background: Patients in cardiac arrest must receive algorithm-based management such as basic life support and advanced (cardiac) life support. International guidelines dictate diagnosing and treating any factor that may have caused the arrest or may be complicating the resuscitation. Ultrasound may be of potential value in this process and can be used in a prehospital setting. The objective is to evaluate the use of prehospital ultrasound during traumatic and non-traumatic CPR and determine its impact on prehospital treatment decisions in a Dutch helicopter emergency medical service (HEMS). **Methods:** We conducted an observational study in cardiac arrest patients, of any cause, in whom the Nijmegen HEMS performed CPR with concurrent echocardiography. The participating physicians had to adhere to Advanced Life Support protocols as per standard operating procedure. Simultaneous with the interruptions of chest compressions to allow for heart rhythm analysis, ultrasound-trained HEMS physicians performed echocardiography according to study protocol. The HEMS nurse and physician recorded patient data and data on impacted (supported or altered) patient treatment decisions.

Results: From February 2014 through November 2016, we included 56 patients who underwent 102 ultrasound examinations. Sixty-two (61%) ultrasound examinations impacted 78 treatment decisions in 49 patients (88%). The impacted treatment was related to termination of CPR in 32 (57%), fluid management (14%), drugs selection and doses (14%), and choice of destination hospital (5%). Causes of cardiac arrest included trauma (48%), cardiac (21%), medical (14%), asphyxia (9%), and other (7%). **Conclusion:** Prehospital echocardiography has an impact on patient treatment and may be a useful tool to support decision-making during CPR in a Dutch HEMS. **Key words:** heart arrest; cardiopulmonary resuscitation; emergency medical services; ultrasonography; clinical decision-making

PREHOSPITAL EMERGENCY CARE 2018; Early Online:1–8

INTRODUCTION

Patients suffering from cardiac arrest must be treated immediately using algorithm-based management such as basic life support (BLS) and advanced life support (ALS). International resuscitation guidelines stress the importance of diagnosing and treating any factor that may have caused the arrest or may be complicating the resuscitative effort (1–4). These guidelines recognize ultrasound to be of potential value in this process.

Peri-resuscitation ultrasound may be useful to identify treatable causes such as pericardial tamponade, cardiogenic shock, myocardial insufficiency, signs of pulmonary embolism, or hypovolemia (5,6). Moreover, it may differentiate between false and true pulseless electrical activity (PEA), a pulseless state respectively with or without any cardiac contractions. Detection of cardiac activity on ultrasound may be an early sign of return of spontaneous circulation (ROSC) and is a good predictor of survival (7,8).

Previous studies have demonstrated the feasibility of the application of ultrasound during in-hospital and out-of-hospital cardiopulmonary resuscitation (CPR) (9). Integrating it in current ALS algorithms is achievable while maintaining strict protocol adherence (10).

Although the added value of ultrasound in ALS has been suggested, the question remains how it affects patient care and decision-making in the specific

Received July 14, 2017 from Department of Anesthesiology, Radboud University Medical Center, Nijmegen, Netherlands (RK, G-JVG, GJS, NH); HEMS Lifeline 3, Volkel Air Force Base, Volkel, Netherlands (CB). Revision received November 9, 2017; accepted for publication December 5, 2017.

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

Address correspondence to Rein Ketelaars, MD, Department of Anesthesiology, Pain and Palliative Medicine, Radboud university medical center, Geert Grooteplein-Zuid 10, 6525 GA Nijmegen, The Netherlands. E-mail: Rein.Ketelaars@radboudumc.nl

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ijpec.

© 2018 Rein Ketelaars, Christian Beekers, Geert-Jan Van Geffen, Gert Jan Scheffer, and Nico Hoogerwerf. Published with license by Taylor & Francis

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (<http://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way.

doi: 10.1080/10903127.2017.1416208

setting of a helicopter emergency medical service (HEMS). We sought to evaluate the use of prehospital ultrasound during traumatic and non-traumatic CPR and determine its impact on patient treatment in a Dutch HEMS.

MATERIALS AND METHODS

Design

We performed an observational study between February 2014 and November 2016. Ethical approval was obtained from the regional ethics review board of Arnhem/Nijmegen and they waived the requirement to obtain written informed consent (2014/112).

Recruitment and Setting

In The Netherlands, four physician-staffed HEMS are operational 24 hours per day, all carrying a portable ultrasound machine. They are supplemental to a high-quality network of paramedic-staffed ground ambulances. The Nijmegen HEMS is stationed at the Volkel Air Force Base, covering an area of approximately 10,000 square kilometers, servicing a population of 4.5 million. Every physician is trained to perform an extended focused assessment with sonography for trauma (eFAST) examination and basic echocardiography. In recent years, our HEMS conducted on average 2341 missions, increasing yearly by 13%. Typically, ground ambulances handle the majority of the resuscitations. However, on their or the dispatch center's request, the HEMS aids in approximately 200 resuscitations including 50 children (< 18 years of age) yearly.

We included every patient that underwent CPR with concurrent echocardiography performed by our HEMS for which a dedicated case report form (CRF) was completed. Exclusion criteria were the discontinuation of CPR or an indication to perform immediate thoracotomy in the case of a (single) penetrating chest injury with loss of circulation no longer than 10 min.

The HEMS database that holds a record of every mission and every patient treated was examined to describe the base population, of which this study's population is a subset.

Protocol

We used two different portable ultrasound machines during the study: a NanoMaxx and a MicroMaxx machine (FUJIFILM SonoSite Inc., Bothell, WA, USA) both equipped with a 5–1 MHz broadband phased array cardiac transducer.

Physicians were requested to treat the cardiac arrest patients in the usual way. ALS protocols with minimal interruptions of chest compressions had to be

respected. Priority had to be given to heart rhythm analysis and defibrillation, establishing IV access, administration of drugs and IV fluids, securing the airway, adequate ventilation, release of (suspected) tension pneumothorax, stopping any life-threatening bleeding, and treatment of other possible reversible causes.

After these interventions, or concurrent when enough caregivers were available, HEMS physicians were requested to perform an ultrasound examination of the heart and pericardium through a sub-xiphoidal view at pre-defined moments in the ALS algorithm. The physician prepared the examination by positioning the ultrasound probe in the subxiphoidal region with an estimated optimum location, probe angle, and machine settings while continuing compressions.

The physician performed the first examination as soon as possible after arrival on-scene, then after every 5 2-min cycles of compressions, and finally, right after return of spontaneous circulation (ROSC) or when considering the termination of CPR, as suggested by Breitzkreutz et al. (5).

The timing of echocardiography had to be in the same window where chest compressions are interrupted to allow for heart rhythm analysis. Interruption of chest compressions had to be kept to a minimum. The algorithm of the American Heart Association (AHA) emphasizes the minimization of the duration time of the interruptions to stay (well) below 10 sec (3). The European Resuscitation Council (ERC) states the entire process of defibrillation should be achievable within a 5-sec interruption (1). We instructed the participating physicians to respect the latter timeframe.

Additional ultrasound examinations of the chest and abdomen were performed depending on the discretion of the physician, but without interrupting chest compressions.

Data Processing

If time allowed, the flight nurses recorded on-scene data simultaneous with every ultrasound examination: time, heart rhythm, palpable pulse, end-tidal CO₂, and the physician-reported ultrasound image quality and global myocardial function.

The CRF, specifically designed for this study, was filled out by the physician after return to base. Data recorded were: (estimated) time of cardiac arrest, start of BLS, initial observed heart rhythm, occurrence and timing of ROSC or termination of resuscitation. Additionally, we recorded ventricular dimensions, pericardial fluid, other findings on ultrasound, impacted decisions, the location where ROSC occurred or the team terminated CPR (e.g., during transport or in-hospital). We scored the perceived ease of the entire procedure on a 1–10 numeric rating scale (NRS) where 1 = extremely difficult and 10 = extremely easy. We

TABLE 1. Demographics

	N (%)	range	Mean \pm SD
Age (years)	56	0–90	42.9 \pm 27.6
0–17	11 (20)		
\geq 18	45 (80)		
Gender			
Male	40 (71)		
Female	16 (29)		
Weight of adults (kg)	44	40–125	83 \pm 18

SD = standard deviation.

encouraged the HEMS-personnel to enter additional free text to supplement or clarify the data.

As part of regular operations, an electronic record is created on every mission and treated patient. Records are stored in the custom-made HEMS database stored on a secure server and backed up daily. We linked the CRFs to the database by mission ID and we extracted additional relevant data: date of birth, sex, estimated body weight, and cause of the cardiac arrest.

Data Analysis

We entered the data from the forms and relevant data from the database into a Castor database (Ciwit B.V., The Netherlands) for secure storage and to comply with good clinical practice standards. After data acquisition was complete, we used IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA) for analysis.

Statistical Analysis

We report normally distributed data as mean \pm standard deviation (SD), and data with a skewed distribution as median with an interquartile range (IQR). We used Tukey's hinge technique to determine the IQR. Spearman correlation coefficient was used to qualify the relationship between body weight and image quality and the reported ease of the procedure. We considered statistical significance at a P value < 0.05 .

RESULTS

Patients' Characteristics

Between February 1, 2014, and November 30, 2016, our HEMS performed 6694 missions in which we treated 3,229 patients. HEMS physicians performed echocardiography during CPR according to study protocol and included 56 patients. A Consort diagram of the study population is displayed in Figure 1. Demographics are displayed in Table 1.

Cardiac Arrest

The causes of cardiac arrest are described for 2 age groups (under and over 18 years) and displayed in

Table 2. The median delay starting BLS after the (estimated) occurrence of cardiac arrest ($n = 50$) was 2.5 min (IQR 0–8.25). CPR continued for a median of 32 min (IQR 23–50). The first ultrasound examination was performed 28 min (IQR 20–39) after the arrest.

ROSC occurred in 14 patients (25%). In 9 patients (16%) ROSC occurred on-scene, in 3 (5%) during transport and in 2 (4%) in the emergency department. Hence, in 42 (75%) patients, circulation never returned. ROSC occurred in 4 of 11 children (36%).

In some, ROSC occurred only temporarily and eventually, the team terminated resuscitation. Overall, 36 (64%) died on-scene, 12 (21%) at the ED and 5 (8%) within 1–4 days after admittance. The latter group suffered from choking ($n = 2$), a cardiac event ($n = 1$), and sudden infant death syndrome (SIDS) ($n = 2$). Three patients (5%) survived and suffered from choking ($n = 2$), and a cardiac event ($n = 1$).

Ultrasound

102 Ultrasound examinations were documented in 56 patients. Image quality was reported good ($n = 60$, 59%), moderate ($n = 30$, 29%) or poor ($n = 12$, 12%). The reported ease of the entire procedure ($n = 40$), comprising of one or more ultrasound examinations, was a median of 7 (IQR 5.50–9.00). In adults, image quality and ease of examinations were weakly negatively correlated to body weight, respectively $r = -.381$ ($r^2 = 0.145$; $p < 0.001$) and $r = -.347$ ($r^2 = 0.120$; $p = 0.045$), as displayed in Figure 2.

Diagnoses made with echocardiography are displayed in Table 3. Additional ultrasound findings of chest and abdomen were pneumothorax (5 patients, 9%), pleural cavity free fluid (2 patients, 4%), intraperitoneal space free fluid (4 patients, 7%), collapse of the inferior vena cava (1 patient, 2%) and other (fractured spleen, hypertrophic ventricle, absent lung sliding because of esophageal intubation; 3 patients, 5%).

Impacted Treatment Decisions

In 49 patients (88%) treatment decisions were impacted or supported based on ultrasound. In 32 patients (57%) ultrasound led to or supported the decision to terminate the resuscitative effort. In 21 patients (38%) it was indicated that at least once (in 29 of 102 examinations (28%)) ultrasound supported the continuation of resuscitation.

Of 102 ultrasound examinations, 62 (61%) impacted or supported management decisions. One examination may have led to multiple changes; 78 impacted decisions were recorded. The number of impacted decisions does not include 29 examinations where physicians reported continuation of resuscitation was influenced by ultrasound. This is not considered impacted treatment, but apparently echocardiography was perceived to have played a role in decision-making.

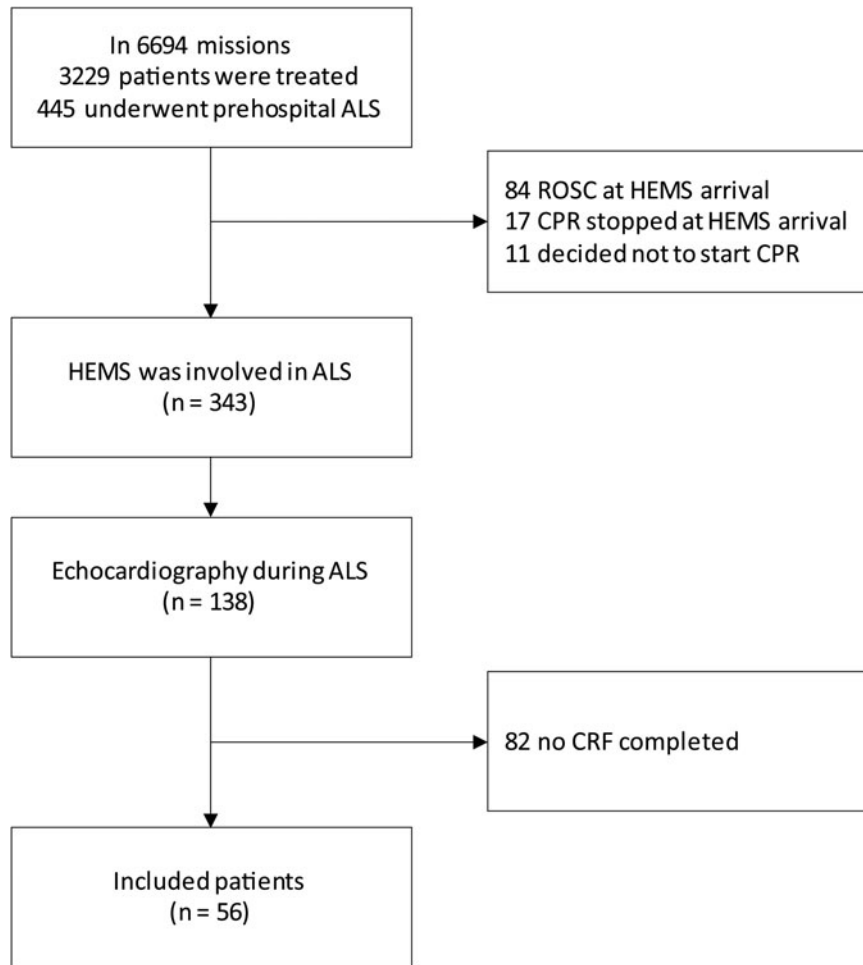


FIGURE 1. Consort diagram of the study population. ALS = Advanced Life Support; ROSC = return of spontaneous circulation; HEMS = helicopter emergency medical service; CPR = cardiopulmonary resuscitation; CRF = case report form.

TABLE 2. Distribution of causes of cardiac arrest (per age category)

Cause of cardiac arrest	Age < 18 years N (%)	Age > 18 years N (%)	Total N (%)
Non-trauma	9	20	29 (52)
Cardiac	0	12 (27)	12 (21)
Medical (non-cardiac)	6 (55)	2 (4)	8 (14)
SIDS	2 (18)	0	2 (4)
Choking and asphyxia	1 (9)	4 (9)	5 (9)
Intoxication	0	1 (2)	1 (2)
Unknown	0	1 (2)	1 (2)
Trauma (high energy)	0	17 (38)	17 (30)
Traffic accident	0	13 (29)	13 (23)
Fall from height	0	2 (4)	2 (4)
Crush injury and asphyxia	0	1 (2)	1 (2)
Impact with a blunt object	0	1 (2)	1 (2)
Trauma (low energy)	2 (18)	8 (18)	10 (18)
Drowning	2 (18)	4 (9)	6 (11)
Hanging	0	3 (7)	3 (5)
Burns and inhalation trauma	0	1 (2)	1 (2)
Total	11 (100)	45 (100)	56 (100)

SIDS = sudden infant death syndrome.

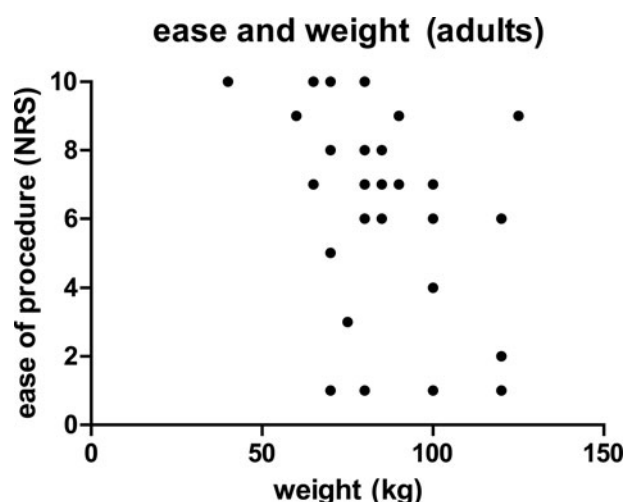


FIGURE 2. Scatterplot of adults' weight (18 years and over) and the ease of performing echocardiography during cardiopulmonary resuscitation. NRS = numeric rating scale (1 = very difficult; 10 = very easy) $r = -.347$ ($r^2 = 0.120$; $P = 0.045$).

All reported decision changes are displayed in Table 4.

DISCUSSION

The main finding of the study is that in 88% of patients' ultrasound guided resuscitation influenced or supported treatment and other decisions. Most frequently reported were termination or continuation of resuscitation and increasing the infusion of IV fluids. This could be expected because prehospital ultrasound may yield information about conditions that are difficult to diagnose by other means during ongoing CPR. These findings suggest that ultrasound can be useful in guiding prehospital CPR management.

TABLE 3. Findings of echocardiography

Observation	Number of U.S. examinations (%)
Cardiac dimensions	
Ventricular filling	
- good	65 (64)
- poor	9 (9)
- no filling	11 (11)
LV dilatation	0
RV dilatation	3 (3)
Could not assess	17 (17)
Global cardiac function	
good	8 (8)
moderate	11 (11)
poor	15 (15)
standstill	62 (61)
could not assess	6 (6)
Pericardial fluid	
absent	87 (85)
some	5 (5)
could not assess	10 (10)

US = ultrasound; LV = left ventricle; RV = right ventricle.

This study confirms the findings of previous studies that have shown that ultrasound can lead to treatment changes. Recently, O'Dochartaigh et al. reported that 25% and 45% of prehospital ultrasound scans supported interventions in trauma and medical patients, respectively (11). The type of ultrasound findings and interventions reported in our study were similar. Breitzkreutz et al. showed altered management in 66% of patients subjected to prehospital peri-resuscitation ultrasound and in 89% of patients undergoing CPR (6). Shokoohi et al. showed changes in management on the ED in undifferentiated hypotension varying between 11.9 and 30.5% for changes in treatment, diagnostic imaging, consultation, and admission location (12). Our observations have added new insight into the role of ultrasound in the specific prehospital population that is being resuscitated by ground ambulance personnel supported by HEMS physicians and nurses.

Strengths and Limitations

The strength of this study is the specific setting in which it has been conducted, which contributes to its originality. These findings might be applied to the more homogeneous team settings across European HEMS. Conversely, it may be difficult to apply these findings to non-physician-staffed HEMS, such as most U.S. services.

Carrying out a prospective study in a physician-staffed helicopter emergency medical service, especially in a CPR scenario, is challenging. Many external factors will influence the mixed team of health care workers and the patient and its environment. Working space and resources are often limited, time pressure is high, and personnel perceive pressure to perform. Furthermore, they are working in surroundings and with colleagues with whom they are often unfamiliar.

The design and specific setting of the study introduce several limitations. We performed echocardiography only in a limited number of cardiac arrest patients. An explanation could be that in our prehospital setting, with a considerable proportion of trauma victims, the quality of ALS is vulnerable to the influence of previously identified unfavorable factors, such as emotional and physical stress of the caregivers, time, and environmental factors. In our operation with its heterogeneous case-mix and within a limited amount of time, essential assessments and actions take precedence over ultrasound. Furthermore, we do not use ultrasound by default (yet) in every patient, let alone in every cardiac arrest case. Therefore, the ultrasound machine is not always brought to the incident site initially. Still, when it is present on-scene, it is not always used. A common scenario is that shortly after arrival on-scene either ROSC occurs or the ground ambulance team has already decided to terminate the resuscitation. Thus, there has not been any opportunity for echocardiography during CPR. Also, we might have omitted to

TABLE 4. Impact of ultrasound on treatment decisions

Change in decision	N (%) US examinations	N (%) Patients
Terminate resuscitation	33 (32)	32 (57)
More intravenous fluid administration	11 (11)	7 (13)
Less intravenous fluid administration	1 (1)	1 (2)
Adjust adrenaline dosage	4 (4)	4 (7)
Start dobutamine (inotropic drugs)	2 (2)	2 (4)
Start phenylephrine (vasopressors)	0	0
Administer heparine	2 (2)	2 (4)
Pericardiocentesis	0	0
Thoracostomy	4 (4)	4 (7)
Insert gastric tube	3 (3)	3 (5)
Transport to different hospital	3 (3)	3 (5)
Provide ED with additional information	4 (4)	4 (7)
Other*	11 (11)	10 (18)
Continue resuscitation†	29 (28)	21 (38)

Note: Multiple impacted or supported decisions can be associated with one examination or one patient.

*Re-intubation because of absent bilateral lung sliding; withholding inotropic drugs; confirmation of tube position; increase noradrenaline dosage; increase cardiac pacing power output; not performing thoracostomies; stop cardiopulmonary resuscitation (ultrasound ROSC).

†Continuation of resuscitation was reported as a decision after echocardiography, but not considered to be a change in treatment decisions.

US = ultrasound; ED = emergency department.

use ultrasound because the cause of cardiac arrest was obvious or further treatment was deemed futile (e.g., a major injury with extensive blood loss).

A major limitation is the high number of missing CRFs. We speculate that some of the reasons might be nonadherence to the protocol, a lack of time due to subsequent missions, or plain forgetfulness. Another could be the dismissal of the entire procedure due to poor image quality, or the impression the scan contributed nothing to patient management. As a result, this might have introduced bias and possibly have led to over or underestimation of overall image quality and impacted decisions.

Unfortunately, in our operation, it is not possible to bring an independent observer on-scene. Therefore, ultrasound images could not be independently reviewed. Also, the impact of ultrasound on patient management was self-reported by the physicians after return to base. This could not be reported more objectively and might introduce bias. For instance, the effort physicians are making to perform echocardiography might make them more inclined to find utility. Or, the delay before the form is filled and other interventions performed in the meantime, might make the physician underestimate any added value when finally filling out the CRF.

The most frequent impacts on management were termination or continuation of resuscitation and increasing the infusion of IV fluids. Although it sometimes appears the obvious choice to terminate resuscitative efforts, this decision is preferably supported by the entire team and is complex and multifactorial (13). The knowledge that sonographic cardiac standstill, in stark contrast to coordinated cardiac activity, predicts very poor (if any) survival improves the process of making a decision (7,8,14). We speculate

this explains the number of times ultrasound supported termination of treatment, although not every observed cardiac standstill justifies this immediately. Additionally, displaying the cardiac activity (or the lack thereof) can be of great value while explaining the prognosis and its implications to relatives and caregivers.

Any positive sign of cardiac activity on ultrasound is encouraging to continue resuscitation (7). However, there can be many other reasons to continue such as improvements of the electrical cardiac activity or exhaled CO₂ concentration. Therefore, we did not include the continuation of resuscitation in the overall amount of changes per patient. Nevertheless, also in this scenario ultrasound has provided additional value to the decision-making process.

Besides providing valuable information about the heart and pericardium, ultrasound in this specific setting is useful detecting unintentional bronchial or even esophageal intubation (leading to hypoxia), (tension) pneumothorax, and causes of hypovolemia such as intraperitoneal bleeding or hemothorax (15–18). This is reflected in the variation in affected treatment decisions.

We reported the ease of performing ultrasound examinations concurrent with CPR to be a median of 7 and there is a negative but weak correlation to body weight. Thus, prehospital cardiac ultrasound performed by HEMS physicians is not perceived to be difficult. Besides the suggestion that body weight complicates ultrasound examination, many other factors may make visualization of the heart more difficult such as environmental factors, sunlight, the presence of clothes, and operating in the tight confinement of an ambulance. Significant difficulties with accessibility or visualization could have resulted in no ultrasound

examinations being made at all, so this score may be biased.

Overall, most frequently reported impact is stopping or continuing treatment, and increasing fluid administration. This is based on the most obvious echocardiographic findings: standstill, contractions, or poor filling of the heart.


This study provides an informative overview of ultrasound and cardiac arrest in a Dutch HEMS setting and it shows that prehospital ultrasound may be of value during CPR. It supports management in the majority of cases and, therefore, we suggest for every comparable HEMS to consider bringing an ultrasound device to cardiac arrest scenarios. On-scene it can then be determined if it is indeed feasible and justifiable to use it.


Because the present study was not designed to determine any effect on outcomes, we were unable to determine the effect of prehospital ultrasound on outcome and survival of resuscitation in our population. Hence, a future randomized experiment might add to our current knowledge regarding the value of ultrasound during CPR. However, such a study will probably be deemed unethical by our HEMS physicians, since they began regarding ultrasound as an essential diagnostic tool.

CONCLUSION

In a physician-staffed HEMS, it is feasible to perform echocardiography in prehospital cardiac arrest. It impacts patient management decisions and may be a useful diagnostic tool to support decision-making in ongoing CPR. Most frequently, ultrasound imaging was used to support the decision to terminate the resuscitation.

ORCID

Rein Ketelaars  <http://orcid.org/0000-0002-3548-0417>

Christian Beekers  <http://orcid.org/0000-0002-8771-3833>

Geert-Jan Van Geffen  <http://orcid.org/0000-0002-9305-124X>

Nico Hoogerwerf  <http://orcid.org/0000-0003-1815-6989>

References

1. Soar J, Nolan JP, Bottiger BW, Perkins GD, Lott C, Carli P, et al. European resuscitation council guidelines for resuscitation 2015: Section 3 Adult Advanced life Support. *Resuscitation*. 2015;95:100–47.
2. Neumar RW, Otto CW, Link MS, Kronick SL, Shuster M, Callaway CW, et al. Part 8: adult advanced cardiovascular life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122(18 Suppl 3):S729–67. doi:10.1161/CIRCULATIONAHA.110.970988. PMID:20956224.
3. Link MS, Berkow LC, Kudenchuk PJ, Halperin HR, Hess EP, Moitra VK, et al. Part 7: adult advanced cardiovascular life support: 2015 American Heart Association Guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation*. 2015;132(18 Suppl 2):S444–64. doi:10.1161/CIR.0000000000000261. PMID:26472995.
4. Soar J, Callaway CW, Aibiki M, Bottiger BW, Brooks SC, Deakin CD, et al. Part 4: advanced life support: 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. *Resuscitation*. 2015;95:e71–120. doi:10.1016/j.resuscitation.2015.07.042. PMID:26477429.
5. Breikreutz R, Walcher F, Seeger FH. Focused echocardiographic evaluation in resuscitation management: concept of an advanced life support-conformed algorithm. *Crit Care Med*. 2007;35(5 Suppl):S150–61. doi:10.1097/01.CCM.0000260626.23848.FC. PMID:17446774.
6. Breikreutz R, Price S, Steiger HV, Seeger FH, Ilper H, Ackermann H, et al. Focused echocardiographic evaluation in life support and peri-resuscitation of emergency patients: a prospective trial. *Resuscitation*. 2010;81(11):1527–33. doi:10.1016/j.resuscitation.2010.07.013. PMID:20801576.
7. Gaspari R, Weekes A, Adhikari S, Noble VE, Nomura JT, Theodoro D, et al. Emergency department point-of-care ultrasound in out-of-hospital and in-ED cardiac arrest. *Resuscitation*. 2016;109:33–9. doi:10.1016/j.resuscitation.2016.09.018. PMID:27693280.
8. Bolvardi E, Pouryaghobi SM, Farzane R, Chokan NM, Ahmadi K, Reihani H. The prognostic value of using ultrasonography in cardiac resuscitation of patients with cardiac arrest. *Int J Biomed Sci*. 2016;12(3):110–4. PMID:27829827.
9. Niendorff DF, Rassias AJ, Palac R, Beach ML, Costa S, Greenberg M. Rapid cardiac ultrasound of inpatients suffering PEA arrest performed by nonexpert sonographers. *Resuscitation*. 2005;67(1):81–7. doi:10.1016/j.resuscitation.2005.04.007. PMID:16199290.
10. Price S, Uddin S, Quinn T. Echocardiography in cardiac arrest. *Curr Opin Crit Care*. 2010;16(3):211–5. doi:10.1097/MCC.0b013e3283399d4c. PMID:20463464.
11. O'Dochartaigh D, Douma M, MacKenzie M. Five-year retrospective review of physician and non-physician performed ultrasound in a Canadian critical care helicopter emergency medical service. *Prehosp Emerg Care*. 2017;21(1):24–31. doi:10.1080/10903127.2016.1204036. PMID:27436374.
12. Shokoohi H, Boniface KS, Pourmand A, Liu YT, Davison DL, Hawkins KD, et al. Bedside ultrasound reduces diagnostic uncertainty and guides resuscitation in patients with undifferentiated hypotension. *Crit Care Med*. 2015;43(12):2562–9. doi:10.1097/CCM.0000000000001285. PMID:26575653.
13. Anderson NE, Gott M, Slark J. Commence, continue, withhold or terminate?: A systematic review of decision-making in out-of-hospital cardiac arrest. *European Journal of Emergency Medicine: Official Journal of the European Society for Emergency Medicine*. 2017;24(2):80–6. PMID:27148638.
14. Cureton EL, Yeung LY, Kwan RO, Miraflor EJ, Sadjadi J, Price DD, et al. The heart of the matter: utility of ultrasound of cardiac activity during traumatic arrest. *The Journal of Trauma and Acute Care Surgery*. 2012;73(1):102–10. doi:10.1097/TA.0b013e3282569ebc. PMID:22743379.
15. Chou EH, Dickman E, Tsou PY, Tessaro M, Tsai YM, Ma MH, et al. Ultrasonography for confirmation of endotracheal tube placement: a systematic review and meta-analysis. *Resuscitation*. 2015;90:97–103. doi:10.1016/j.resuscitation.2015.02.013. PMID:25711517.

16. Sim SS, Lien WC, Chou HC, Chong KM, Liu SH, Wang CH, et al. Ultrasonographic lung sliding sign in confirming proper endotracheal intubation during emergency intubation. *Resuscitation*. 2012;83(3):307–12. doi:[10.1016/j.resuscitation.2011.11.010](https://doi.org/10.1016/j.resuscitation.2011.11.010). PMID:22138058.
17. Ramsingh D, Frank E, Haughton R, Schilling J, Gimenez KM, Banh E, et al. Auscultation versus point-of-care ultrasound to determine endotracheal versus bronchial intubation: a diagnostic accuracy study. *Anesthesiology*. 2016;124(5):1012–20. doi:[10.1097/ALN.0000000000001073](https://doi.org/10.1097/ALN.0000000000001073). PMID:26950708.
18. Kirkpatrick AW. Clinician-performed focused sonography for the resuscitation of trauma. *Crit Care Med*. 2007;35(5 Suppl):S162–72. doi:[10.1097/01.CCM.0000260627.97284.5D](https://doi.org/10.1097/01.CCM.0000260627.97284.5D). PMID:17446775.